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Vinyl Plastics as Materials of Construction

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A sufficiently long period of time has now elapsed since the first major impact of plastic products was felt in almost every phase of consumer and industry relations, so that it is possible to give a rather good evaluation of the import of plastics for industry and consumer alike.

With any new product or class of products, the very real danger exists that over-enthusiasm in product development by manufacturers, as well as in product acceptance by the public may lead to hasty decisions, which in turn result in regrettable consequences.

While American Industry had become highly conservative during the last 30 years or so in promoting new products to the consumer stage, the circumstances surrounding the birth of large scale manufacture and marketing of plastic products were of such a nature that untimely release of as yet immature consumer products took place on a vast scale. The pressure of approaching war in the late thirties was to a large extent responsible for "quicky" developments in plastics utilization which were of unproven merit. The result was inevitable. Adverse customer reaction set in to such an extent that the plastics industry as a whole might have suffered a serious blow, had it not been for the advent of the war and the resulting urgent need for synthetics as substitutes for many critical materials.

The reason that the plastics industry survived and continued to grow lies in the fact that the plastic materials possess inherently sound properties which can be of great utility if properly adapted to the intended application.

Of the unusually large number of successful applications of plastics, one of the most recent developments is their use as materials of construction. While both thermosetting and thermoplastic materials find many uses in this respect, as for instance, in housing, automobiles, furniture, etc., the thermoplastics, and in particular the "vinyls" are finding increasing utility in industrial applications, where their physical properties and their unique corrosion resistant behavior often make them the material of paramount choice.

In regard to the possibility of industrial applications, the field of thermoplastics narrows down to just about four types of materials, all of which are basically derivatives of ethylene. They are the polymers of ethylene (polyethylene, Polythene), tetrafluoroethylene (Teflon), trifluoromonochlorethylene (Kel-F) and vinyl

chloride (polyvinyl chloride polymers and certain copolymers). Developments in diisocyanate polymers (polyurethanes) acrylonitrile polymers (Orlon, Vinyon) and terephthalic acid polymers (Terylene) are too new to permit any prediction as to their possible utilization as industrial materials of construction.

The vinyl chloride polymers present tonnagewise the largest class of materials under consideration and therefore are readily available in larger quantities and at reasonable cost. Consequently, they are of greater interest from an application standpoint, and the remainder of the discussion will be limited to their applications as materials of construction.

General Characteristics

At the present time the vinyl chloride type resins which are commercially available in the United States, are marketed under the following trade names: Geon, Marvinol, Pliovic, Ultron and Vinylite. Foreign resins falling in this class, which, however, may not be readily available in quantity, are Lucoflex (trade name for a compound) and the Pechiney resins in France and the various Igelite types, as well as the resins marketed under the Vinnol and Astralon trade names in Germany.

In most instances the approximate compositions of the resins are known so that it can readily be established if they are essentially straight vinyl chloride polymers or copolymers of vinyl chloride and co-monomers such as vinyl acetate, vinylidene chloride, etc.

So far, the most extensive investigations on the use of vinyl chloride polymers as materials of construction have been carried out in Germany. A comprehensive coverage of the available information was published in two German books in 1943 and 1944, respectively (References 1 and 2). This work definitely points to the fact that the most suitable types of vinyl resins are those made from vinyl chloride alone without the use of any co-monomer. This seems to be a rather sound conclusion, as the introduction into the polymer molecule of what might be considered a monomer with more reactive side chains, could be expected to contribute to greater reactivity of the resultant polymer.

A further point which must be considered is the fact that the processing of the polymer resin powder into a structural shape suitable for practical application, necessitates the use of at least some processing aids. Naturally, it is desirable to have the finished article consist of essentially pure fused (and solidified) polymer, but in order to be able to carry out the necessary processing operations, such as milling, extruding, forming, etc., some additives such as

stabilizers and lubricants must be employed. The judicious choice of these additives is very important in the formulation of the so-called compound (the raw material mixture ready for processing), as the nature of the materials which are added to the vinyl resin can have a pronounced effect upon its subsequent behavior in actual use.

As the application as materials of construction usually requires a rather high degree of rigidity, the use of plasticizers is held to a minimum, and whenever possible no plasticizers whatever are incorporated into the compound.

Resistance to fluid media

The behavior of vinyl chloride polymers towards aqueous media, such as solutions of salts, alkalies and acids, is unusual, in so far as the resistance to degradation increases with increasing concentration of the solutions. This, of course, is exactly opposite to the general behavior of metallic materials of construction.

However, this seemingly anomalous behavior is readily understood, once it is realized that vinyl polymers possess a certain sensitivity to water itself, while the chlorinated organic substance is insensitive to the dissolved materials. Consequently, the degree of attack is a direct function of the amount of water in the solution. Whereas, corrosive attack of metals is bound up intimately with electrolytic phenomena, such is not the case with the vinyl polymers because of their non-conductive nature, and any attack which they might suffer is due entirely to the direct influence of corrosive media upon their polymeric structure.

As far as resistance to organic solvents is concerned the picture is entirely normal. Such solvents exert a dissolving or solvating action on the organic polymer, which differs in degree with the type and nature of the solvent.

The difference in the action of water and solvents is fundamental in nature. Water will penetrate into the solid polymer by diffusion and continue to diffuse through the polymeric network, probably only in the interstices between the polymer molecules. In this manner it can occasion a swelling and general weakening of the solid structure. This purely physical penetration is essentially reversible in nature and the mechanical properties of the polymer can be almost completely reestablished after removal of the water.

With organic solvents however, especially those which are fairly active solvating agents, the initial diffusion of solvent is thought to be followed by reaction between the solvent and the secondary valence forces of the polymer molecules. In this manner each mole-

cule will in time become surrounded by a solvated layer or a gel-layer and the resultant attack will be evidenced by serious disruption of the structure and fundamental changes in physical properties. Figure 1 presents a diagrammatic picture of swelling phenomena, with and without solvation.

Swelling without solvation *Swelling with solvation*

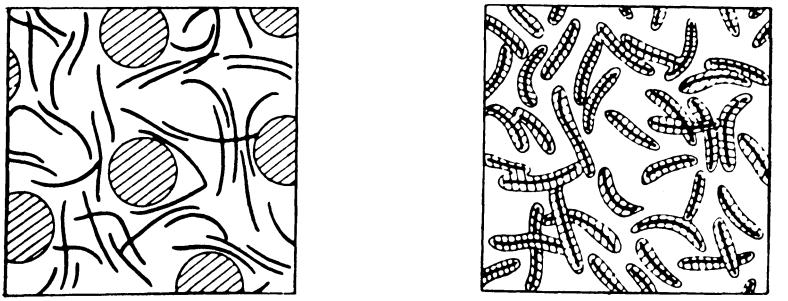

Figure 1. Diagrammatic presentation of swelling phenomena. (Reference 2)

Resistance to specific media

The basic behavior of vinyl polymers towards organic solvents, both liquid and gaseous, will in general result in such a degree of attack, that the use of the polymers with organics is limited to only a few isolated cases, where the attack is of a very low degree.

Therefore, the main field of application as materials of construction is with aqueous media of essentially inorganic nature. While this is a necessary limitation, the potential scope of applications still is extremely great, because it is just in such instances that the metals are most vulnerable.

In view of the fact, that the most serious attack is occasioned by water itself, it will be worth while to first consider the effect of water only upon the polymer. Physical properties, as one would expect, deteriorate with length of exposure at a given temperature, and with higher temperature for definite exposure times. As a general value, a temperature of about 40°C. can be considered as a limit for extended exposure. The effect of temperature is, of course, twofold, in that elevated temperature will promote the rate of diffusion of water into the polymer structure, and also will affect the polymer properties as a result of the thermoplastic nature of the materials. Figure 2 shows the effect of exposure to water at 60°C. upon various physical properties of a polyvinylchloride plastic composition.

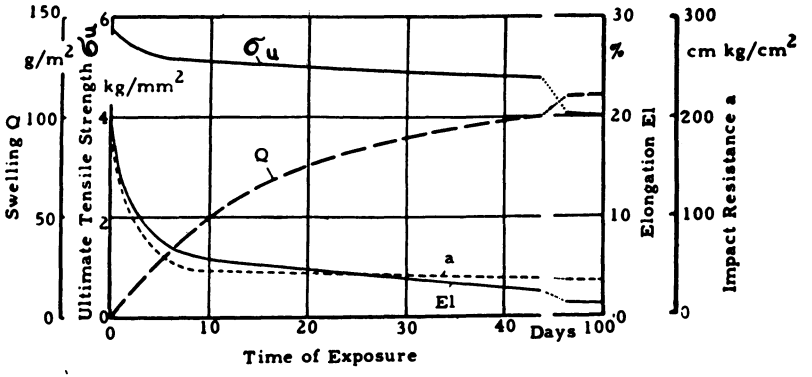

Figure 2. Effect of Exposure to Water at 60°C. on Polyvinylchloride Composition. (Reference 2)

When it comes to aqueous solutions, the resistance of the polymers to attack is conditioned strictly by the water content of the solutions. The temperature effect, of course, is essentially the same as with pure water. A very great variety of inorganic alkalies and acids in form of their aqueous solutions can be handled in equipment constructed of vinyl chloride polymer. As pointed out previously concentrated solutions are handled more easily than dilute solutions and the permissible temperature of exposure is also higher. Extended use at about 60°C. is usually possible. As one would expect, limitations are imposed by the nature of the solutions, in that materials which are of an oxidizing nature will result in oxida-

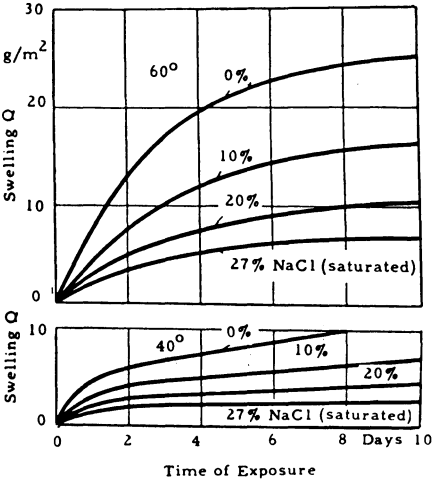

Figure 3. Swelling of Polyvinylchloride Composition in Salt Solutions. (Reference 2)

tive degradation of the polymer under conditions which will favor chemical reaction. Such attack is likely to occur with nitric acid of a strength greater than about 50%, fuming sulfuric acid, chlorine water and similar substances. Figure 3 shows the swelling behavior of a polyvinylchloride composition upon exposure to sodium chloride solutions. Similar performance curves are obtained for aqueous solutions of acids and alkalies.

Resistance to attack by gases, especially dry gases, likewise, is of a high order, so that applications at temperatures up to about 60°C. are also possible. Moist gases, in general, are more corrosive and the allowable exposure temperatures are in the range of 20 to 40°C.

While many organic acids and even alcohols and aldehydes can be handled at temperatures up to 40°C., and some even at 60°C., the usual types of organic solvents attack the polymers so severely that they cannot be used in installations where such solvents are encountered. A notable exception is the behavior of mineral oils and to some extent that of gasolines with a low content of aromatics. Most of the other solvents, such as benzene, toluene, carbon tetrachloride, carbon disulfide, etc. cause an appreciable decrease in tensile strength and corresponding increase in elongation, so that the polymers in contact with these solvents would be subject to rapid failure in use. Figure 4 shows the effect of various organic solvents upon a polyvinylchloride composition.

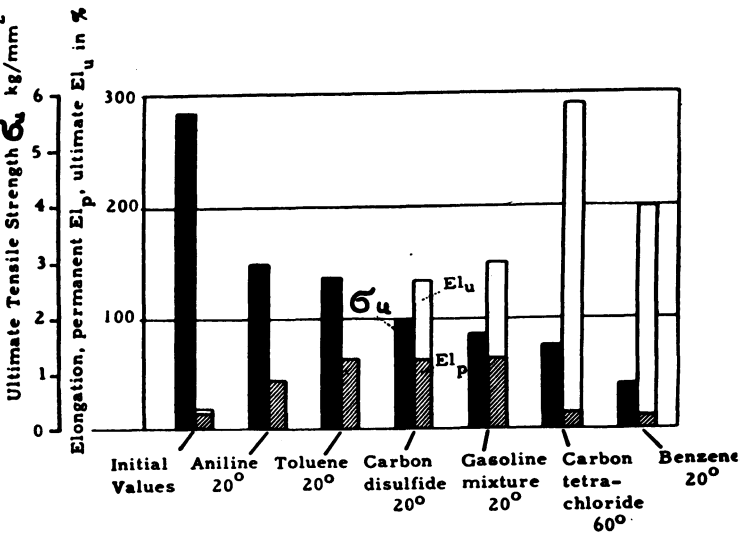

Figure 4. Effect of Organic Solvents upon Properties of a Polyvinylchloride Composition. (Reference 2)

Design and use of structural parts

The very fact that vinyl chloride polymers are thermoplastic materials, emphasizes the importance of temperature in both the forming and shaping of a structural part and in the use of such a part. A structural shape, as well as any other shape made of plastic material, be it pliable or rigid, really represents a "frozen" state of the respective material combinations. As long as the material remains below its freezing or solidification point, it can perform the variety of functions for which it has been designed. When the temperature, however, approaches the softening point, which for a straight vinyl chloride polymer is about 80°C., the material will weaken at a progressively increasing rate and of course become unsuitable in any application.

In addition to the important effect of temperature, another factor has to be considered in all applications where vinyl chloride polymers have to carry a load or have to withstand pressure. It is the effect of time of loading upon the strength of the material, that is, the phenomenon of creeping. While this factor is also encountered with metals, where, however, it becomes noticeable only at high temperatures, creeping of plastic structural shapes must be taken into consideration at any temperature level.

Early experiences in the use of plastics often left the impression that failure of parts had been due to embrittlement. As a result of many years of careful observation, however, the fact has been established that embrittlement is not a factor in the failure, unless the conditions of exposure were such that chemical deterioration could have occurred. What actually had been happening, was that the "strength-time" function, or so-called endurance strength, had been exceeded, so that the action of the load over a period of time led to a weakening of the molecular structure which then resulted in failure of the part.

It is believed that the effect of time on a plastic shape under stress is to cause intermolecular migration or disentanglement of the normally coiled polymer molecules. This phenomenon will get underway at a heavily stressed section and will continue to spread until sudden rupture occurs. The presence of notches or surface defects will contribute materially to the onset of the molecular migration, and it has been recognized for some time that the shaping and forming of plastic structural parts must be carried out in such a manner as to avoid notches, defects and sudden changes in cross-sectional area.

Plastics technology, therefore, has developed a rather compre-

hensive system for the proper design of structural parts. Some of the most important rules which have to be followed are:

1) Changes in cross-sectional area must be gradual;
2) where sudden changes in shape cannot be avoided adequate fillet curvatures must be used;
3) avoid drilled holes as much as possible, at or near stressed contours;
4) avoid the use of threads whenever possible; if threads cannot be avoided, they should be cut upon reinforced cross-sections and have a round contour;
5) design thread assemblies in such a manner so that they cannot be tightened excessively.

Additional precautions which must be used in the construction and assembly of structural parts are the proper fitting or matching of connecting parts, proper clearance allowances for thermal expansion of parts such as piping, tank lining, etc., and the placing of

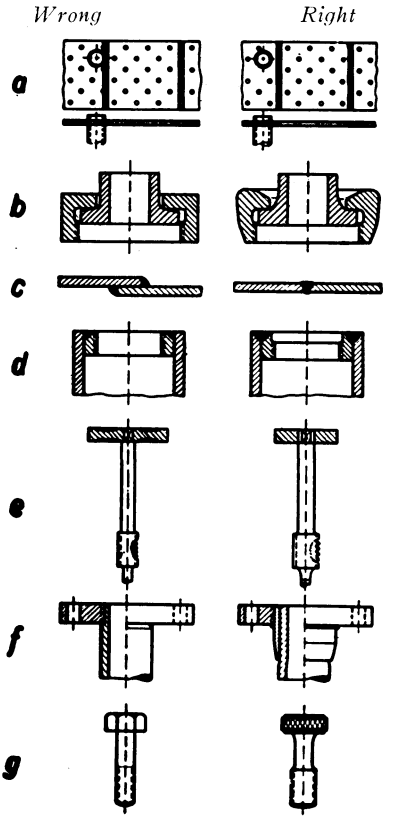

Figure 5. Examples of Shaping of Structural Parts. (Reference 2)

reinforced sections at the points of maximum stress. Examples of proper and improper shaping of structural parts are shown in Figure 5. The left-hand column shows the wrong way; the right-hand column show the right way.

Welding of vinyl chloride plastics

A variety of methods have been developed for welding vinyl chloride plastics, but the most successful process has been the hot-air welding method. Other thermoplastic materials also can be welded in this manner. While thin sections of plastics, such as films and sheets, can be welded together by a relatively simple heat-sealing procedure, the thicker sections usually encountered in structural parts, cannot be bonded in this manner. The main reason is, that the relatively low thermal conductivity of the polymeric material does not permit the heating of the entire cross-section to a sufficiently high and even temperature, without overheating the surfaces and thus causing thermal degradation.

Therefore, a welding procedure analogous to the welding of metals became necessary. In this process "welding rods" of plastic are used which correspond in composition to that of the base material. The source of heat is a hot air jet which takes the place of the usual welding torch. In the actual welding process only immediately adjacent surfaces are heated above the softening temperatures and the weld is filled in layers, much as one might apply multiple layers of sealing wax.

It is to be expected that such a technique requires a considerable degree of operational skill and this is indeed the case. The quality of welds made in this manner is usually expressed by means of a "quality factor" which represents the ratio of tensile strengths of weld and base material respectively. Skilled operators are able to consistently perform at quality factors of about 0.8. The most common flaws which are encountered are bonding defects and overheating of either base material or welding rod, or both.

In conclusion, it can be stated, that modern plastics technology is based on a rather thorough understanding of the principles which underlie the manufacture and utilization of structural parts and therefore it can be expected that plastics, in particular vinyl chloride plastics, will find increasing uses as materials of construction.

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